

An MHD-driven Disk Wind Outflow in SDSS J0300+0048?

Patrick B. Hall

Princeton University Observatory, Princeton, NJ 08544-1001, USA,
and Departamento de Astronomía y Astrofísica, Facultad de Física,
Pontificia Universidad Católica de Chile, Casilla 306, Santiago 22, Chile

Damien Hutsemékers

Research Associate FNRS, University of Liège, Allée du 6 août 17, Bat.
5c, 4000 Liège, Belgium

Abstract. The outflow in SDSS J0300+0048 has the highest column density yet reported for a broad absorption line quasar. The absorption from different ions is also segregated as a function of velocity in a way that can only be explained by a disk wind outflow. Furthermore, the presence of the such large column densities of gas at the high observed outflow velocities may be incompatible with purely radiative acceleration. MHD contributions to the acceleration should be considered seriously.

1. Observations and Implications

SDSS J030000.56+004828.0 (Fig. 1) is a luminous, “overlapping-trough” broad absorption line (BAL) quasar (Hall et al. 2002) and one of only a handful of Ca II BAL quasars known. High-resolution spectroscopy has been obtained for this object using the Ultraviolet Visual Echelle Spectrograph on the ESO VLT (Hall et al. 2003). Figure 2 shows the UVES spectrum around five important transitions, with outflow velocity increasing to the left. The Ca II, Mg II, and Mg I column densities in this object are the largest reported to date for any BAL outflow. The column density of metals is ~ 200 times higher than in the only other Ca II BAL studied at high resolution, QSO J2359–1241 (Arav et al. 2001).

Figure 3 sketches the inferred structure of the outflow in SDSS J0300+0048. The large column density of Ca II observed in this object can only exist in gas well shielded by an H I ionization front (Ferland & Persson 1989), and Ca II is only seen at the lowest line-of-sight velocities in the outflow. Therefore, the lowest-velocity outflowing gas is farthest from the quasar. This result is very unlikely if BAL outflows are nearly spherical “cocoons” of dusty gas. On the other hand, it is easily understood in disk-wind models where the gas originating closest to the quasar is accelerated to the highest velocities, and where we can look across the streamlines of the outflow instead of just down along them. There is considerable other evidence for a disk wind outflow in this object:

- looking across the streamlines can explain why the lowest velocity gas in the outflow is “detached” (blueshifted from the systemic redshift) by $\sim 1650 \text{ km s}^{-1}$ — the gas undergoes acceleration before it crosses our line of sight.

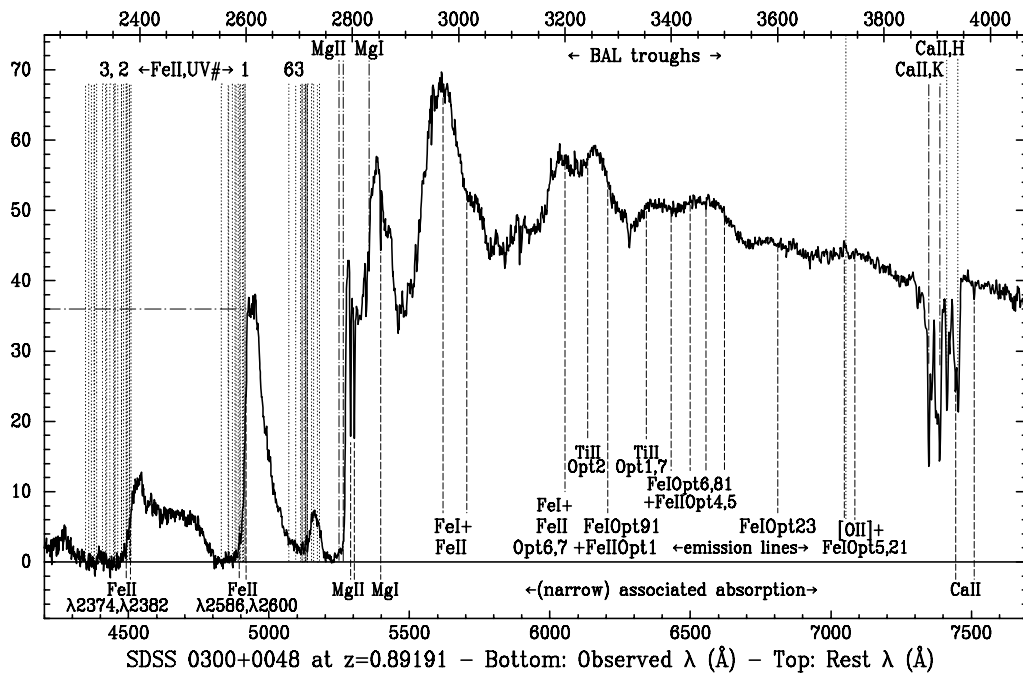


Figure 1. Low-resolution spectrum of SDSS J0300+0048.

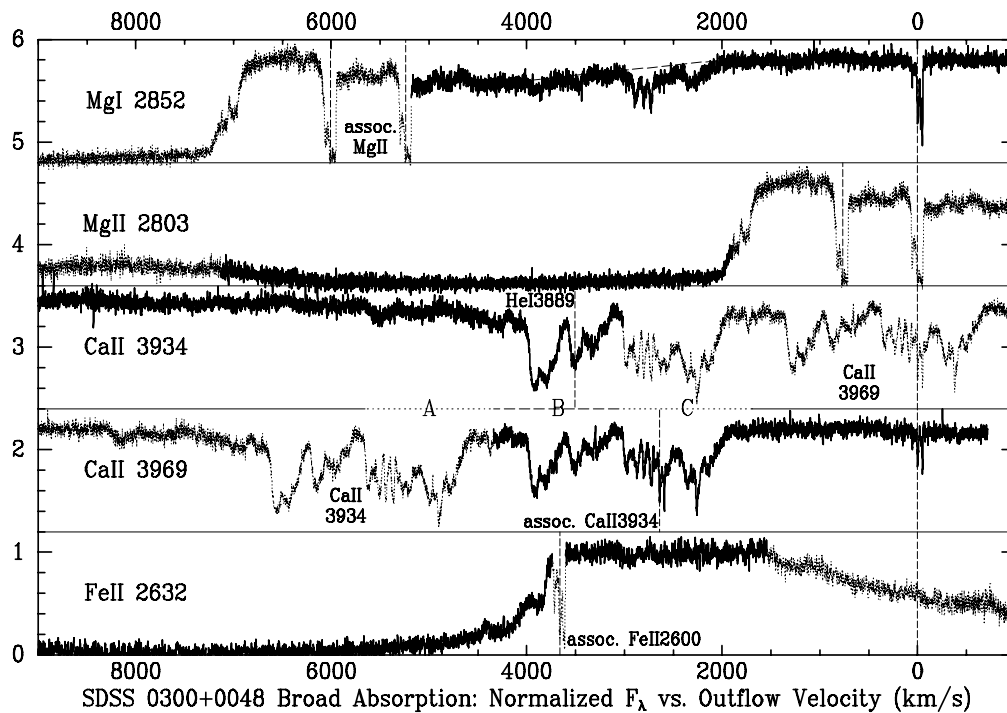


Figure 2. Portions of the high-resolution spectrum of SDSS J0300+0048.

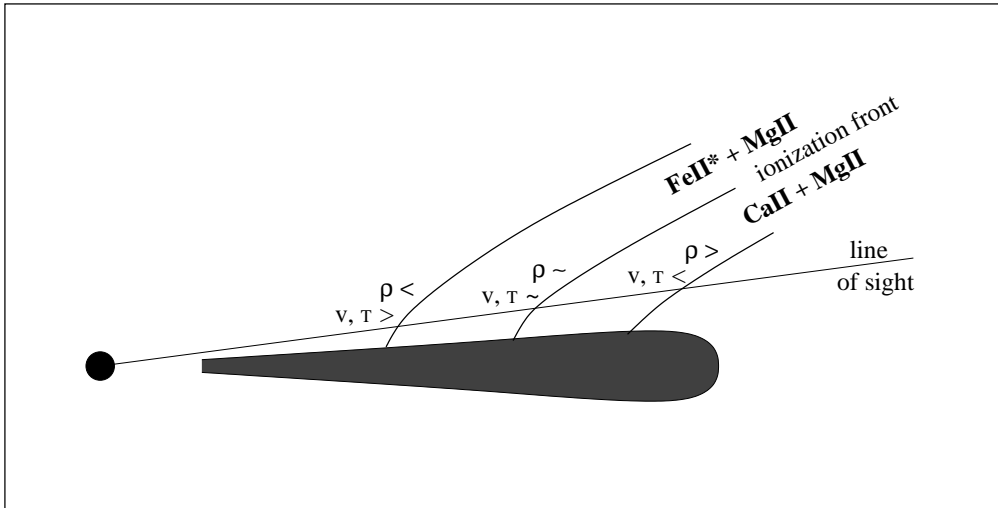


Figure 3. The thin line shows our sightline to the black hole and central continuum source (black dot). The curved lines show the streamlines of wind from the accretion disk (half of which is shown, in profile, as the elongated slab). The symbols beside each streamline show how the density (ρ), velocity (v) and temperature (T) increase ($>$), decrease ($<$), or remain the same (\sim) *between* streamlines along the line of sight (changes different from those *along* an individual streamline, where v and T always increase and ρ always decreases with increasing radial distance). In this Figure, the H I ionization front is assumed to be coincident with a streamline, though that may not be the case in reality. Inside this front around the quasar we observe Mg II and Fe II* in absorption, while outside it we observe Mg II and Ca II in absorption.

- The lowest velocity BAL region produces strong Ca II absorption but no significant excited Fe II (Fe II*) absorption, while the higher velocity excited Fe II absorption region produces very little Ca II. Figure 3 shows how this segregation can arise naturally in a disk wind model. The density at the base of the wind (the surface of the accretion disk) increases with radius over the relevant range of radii, at least in a standard thin disk model (Shakura & Sunyaev 1973). Thus, both the Fe II* and Ca II BAL regions likely have densities high enough to populate excited levels of Fe II, but the Ca II BAL region must have a temperature low enough ($T < 1000$ K) to prevent them from being significantly populated. Outflowing clouds in a “cocoon” cannot explain this segregation unless the lowest velocity clouds are farthest from the quasar (which would be rather contrived for a cocoon model). Otherwise, gas shielded by optically thick, low-velocity Ca II clouds would produce Ca II absorption at high velocities as well.

This model predicts that the Mg II absorption at velocities $v < 4000 \text{ km s}^{-1}$ should not be accompanied by C IV absorption. Such segregation of Mg II and C IV is not usually observed in quasars. However, that could be because most lines of sight through BAL quasar outflows are less highly inclined relative to the outflow streamlines than is our line of sight in SDSS J0300+0048. Since

acceleration occurs along the streamlines, lines of sight oriented along them may tend show all ions present in absorption at a range of velocities.

Finally, the acceleration of a large column of velocity-segregated, very low-ionization gas to the observed velocities of up to 4000 km s^{-1} may require more than continuum and line radiation pressure on atoms and ions. Radiation pressure on ionized gas can push accompanying neutral gas along in an outflow, but that scenario would not produce the velocity-segregated outflow seen in SDSS J0300+0048. Continuum radiation pressure on neutral atoms is unlikely to produce an acceleration comparable to that from line pressure on ionized gas, but radiation pressure on dust in the low-ionization zones of the outflow may produce significant acceleration (Dopita et al. 2002).

Magnetohydrodynamical effects (e.g., magnetocentrifugal acceleration) can also contribute to the acceleration of gas even if the ionization fraction is very small. Moreover, we note that MHD acceleration would be *required* if the X-ray absorbing column of $N_H \simeq 3.5 \times 10^{24} \text{ cm}^{-2}$ in this object (Hall et al., in preparation) is outflowing rather than stationary. Even assuming 100% covering and absorption of 100% of the radiation of a quasar radiating at the Eddington limit, a column density of gas $N_H > 1.43 \times 10^{24} \text{ cm}^{-2}$ cannot be accelerated away from a quasar by radiation alone (Hamann et al. 2002).

Unambiguous evidence of MHD driving requires finding a BAL quasar with X-ray absorbing column $N_H > 1.43 \times 10^{24} \text{ cm}^{-2}$ *and* narrow, detached absorption troughs which trace the X-ray absorbing column. Detecting that high a column in outflow (rather than at the systemic redshift) would unambiguously point to MHD acceleration in quasar outflows. SBS 1542+541 shows detached UV troughs of ions up to Si XII (Telfer et al. 1998), but its $N_H \leq 10^{23} \text{ cm}^{-2}$ does not *require* MHD acceleration. More promising may be the recently discovered detached X-ray BAL troughs (from ions up to Fe XXVI). The highest column density reported among 4 or 5 such objects is $N_H \simeq 5.7 \times 10^{23} \text{ cm}^{-2}$ (PDS 456; Reeves et al. 2003), within a factor of 2.5 of that needed to confirm MHD driving.

Acknowledgments. Funding for the creation and distribution of the SDSS Archive (<http://www.sdss.org/>) has been provided by the Alfred P. Sloan Foundation, the Participating Institutions, the National Aeronautics and Space Administration, the National Science Foundation, the U.S. Department of Energy, the Japanese Monbukagakusho, and the Max Planck Society.

References

- Arav, N., et al. 2001, ApJ, 546, 140
- Dopita, M. A., et al. 2002, ApJ, 572, 753
- Ferland, G. J., & Persson, S. E. 1989, ApJ, 347, 656
- Hall, P. B., Anderson, S., Strauss, M., York, D., et al. 2002, ApJS, 141, 267
- Hall, P. B., Hutsemékers, D., et al. 2003, ApJ, 593, 189
- Hamann, F., et al. 2002, in X-ray Spectroscopy of AGN with Chandra and XMM-Newton, eds. T. Boller et al. (Garching: MPE), 121
- Reeves, J. N., O'Brien, P. T., & Ward, M. J. 2003, ApJ, 593, L65
- Shakura, N. I., & Sunyaev, R. A. 1973, A&A, 24, 337
- Telfer, R. C., et al. 1998, ApJ, 509, 132